SUSY Searches Using Photons at the Tevatron

presented by

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for the

DØ and CDF collaborations

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Outline

- Prompt photon production in SUSY models
  - Gauge mediated SUSY breaking
  - Radiative neutralino decay
- CDF experiment
  - Diphoton + missing E_T search
  - The *ee* $\gamma\gamma$ missing E_T candidate
- DØ experiment
  - Diphoton + missing E_T search (summary)
  - Photon + jets + missing E_T search

SUSY Sources of Photons

Two mechanisms have been extensively discussed in the literature

- Gauge mediated supersymmetry breaking
- Radiative decay of neutralinos

Gauge Mediated SUSY

- If SUSY exists it must be broken
- SUSY is broken in a hidden sector
- Many variations of gravity-mediated models of SUSY breaking studied. Common feature: missing transverse momentum (ME_T) due to escape of weakly-interacting stable LSP

Alternative mechanism

- SUSY breaking via gauge interactions
  - SUSY breaking scale $\Lambda \sim 100$ TeV
  - $M_{gravitino} \sim 4.2 \times 10^{-5} (\Lambda/500 \text{ GeV})^2$ eV
    Gravitino is very light $\Rightarrow$ LSP
- Lightest superpartner for a normal particle (NLSP) $\Rightarrow$ lightest neutralino
- Neutralino $\rightarrow$ photon + gravitino
- In such a model, SUSY pair production yields 2 photons in addition to ME_T

Radiative Neutralino Decay

In gravity-mediated models, a different process can yield photons

- Ambrosanio *et al.*[1,2] suggested an explanation of the CDF $ee\gamma\gamma ME_T$ candidate

$$N_2 \text{ dominantly gaugino}$$
$$N_1 \text{ dominantly Higgsino}$$
$$BR(N_2 \to \gamma N_1) \approx 100\%$$

- One photon is produced from each N_2 decay; one or more photons can appear in the final state

[1] Phys. Rev. Letters **76**, 3498 (1996)
[2] Phys. Rev. **D55**, 1372 (1997)

MSSM Framework

MSSM = minimal (particle content) SUSY extension to the SM;
SM + 2 Higgs doublets + partners

- Gaugino-Higgsino sector specified by 4 parameters
  - **M_1 = U(1)$_Y$ mass parameter**
  - **M_2 = SU(2)$_L$ mass parameter**
  - **tan(β) = ratio of Higgs doublets VEVs**
  - **μ = Higgsino mixing parameter**
- Partners of gauge bosons & Higgs bosons mix
  - Four neutralinos $\boxed{N_i\text{, also known as } \tilde{\chi}_i^0}$
  - Two charginos $\boxed{C_i\text{, also known as } \tilde{\chi}_i^\pm}$

$\gamma\gamma$ Data Collection

Strategy: look for any deviations from SM predictions, for all $\gamma\gamma$ final states [1,2]

- 85 pb^{-1} integrated luminosity
- L1 trigger
  2 EM trigger towers E_T> 4 GeV, $|\eta|$<1.0
- L2 trigger
  2 EM clusters E_T> 10 GeV + isolation
  (good background rejection at low E_T)
  or
  2 EM clusters E_T > 16 GeV
  (high efficiency at high E_T)
- L3 trigger
  cluster energies with offline algorithm
  above 10 (16) GeV thresholds

[1] hep-ex/9801019, accepted by Phys. Rev. Letters
[2] hep-ex/9806034, submitted to Phys. Rev. **D**

Photon ID and Isolation

- Photon candidate: energy cluster in central EM calorimeter
- Photon identification
  - No associated track with $p_T > 1$ GeV; no more than 1 track with $p_T \leq 1$ GeV
  - Shower shape consistent with γ
- Photon isolation
  - Low E_T: isolation in calorimeter
  - High E_T: isolation in calorimeter and tracking system
  - Reject candidates with a 2nd EM cluster in strip chambers ($\pi^0 \rightarrow \gamma\gamma$)

$\gamma\gamma$ Event Selection

Global event requirements

- Projective geometry: $|z_{prim.\ vert.}| < 60$ cm
- Cosmics: no central hadronic calorimeter tower with E > 1 GeV out of 55 ns time window

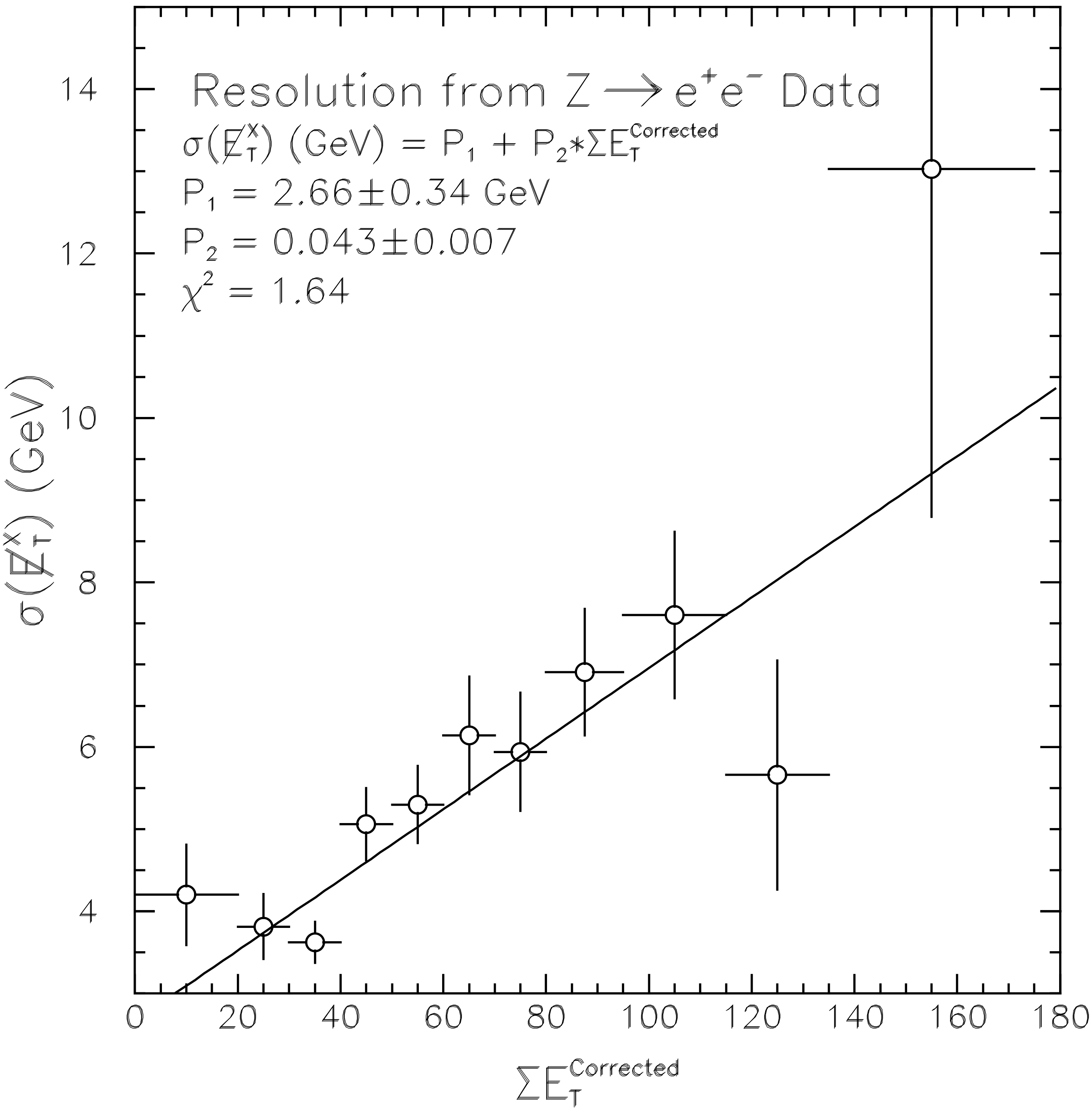
Efficiencies

- Trigger
  - Low threshold: 96 ±1%
  - High threshold: 100%
- Total photon ID + isolation
  - Low threshold: 68 ±3%
  - High threshold: 84 ±4%
- Vertex requirement: 93%
- Energy-out-of-time: 98%
- Diphoton sample: 2239 events
  - Prompt photon purity: 15 ± 4%

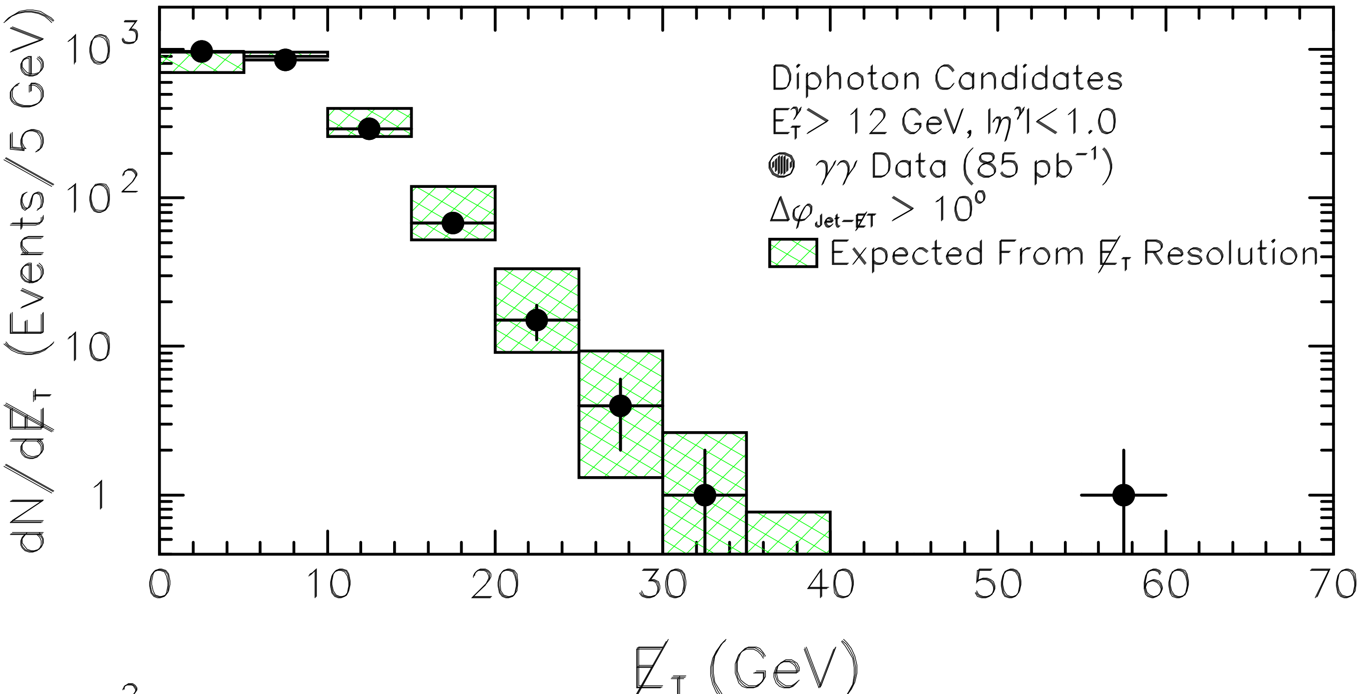
$\gamma\gamma$ + ME_T Search

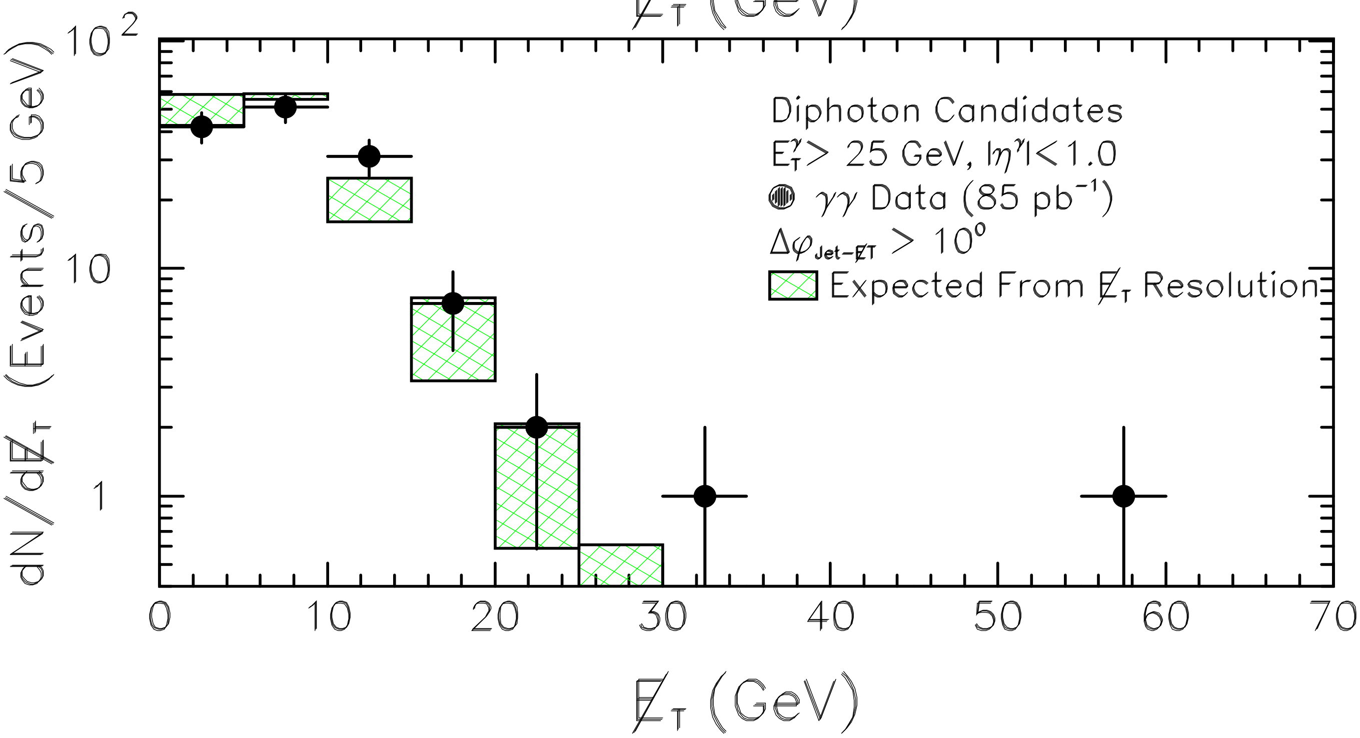
- Primary SUSY tactic: look for ME_T
- 2γ $E_T > 12$, $ME_T > 35$ GeV
- Background: mistaken ME_T from jets
  - Require $|\Delta\phi(\text{jet}, ME_T)| > 10°$
- Study ME_T resolution in $Z \rightarrow ee$ events
- SM diphotons have no intrinsic ME_T — predict ME_T distribution from resolution
- Expected background: 0.5 ± 0.1 event
- Observe: 1 exceptional event

ME_T Resolution



γγ + ME$_T$ Data Sample



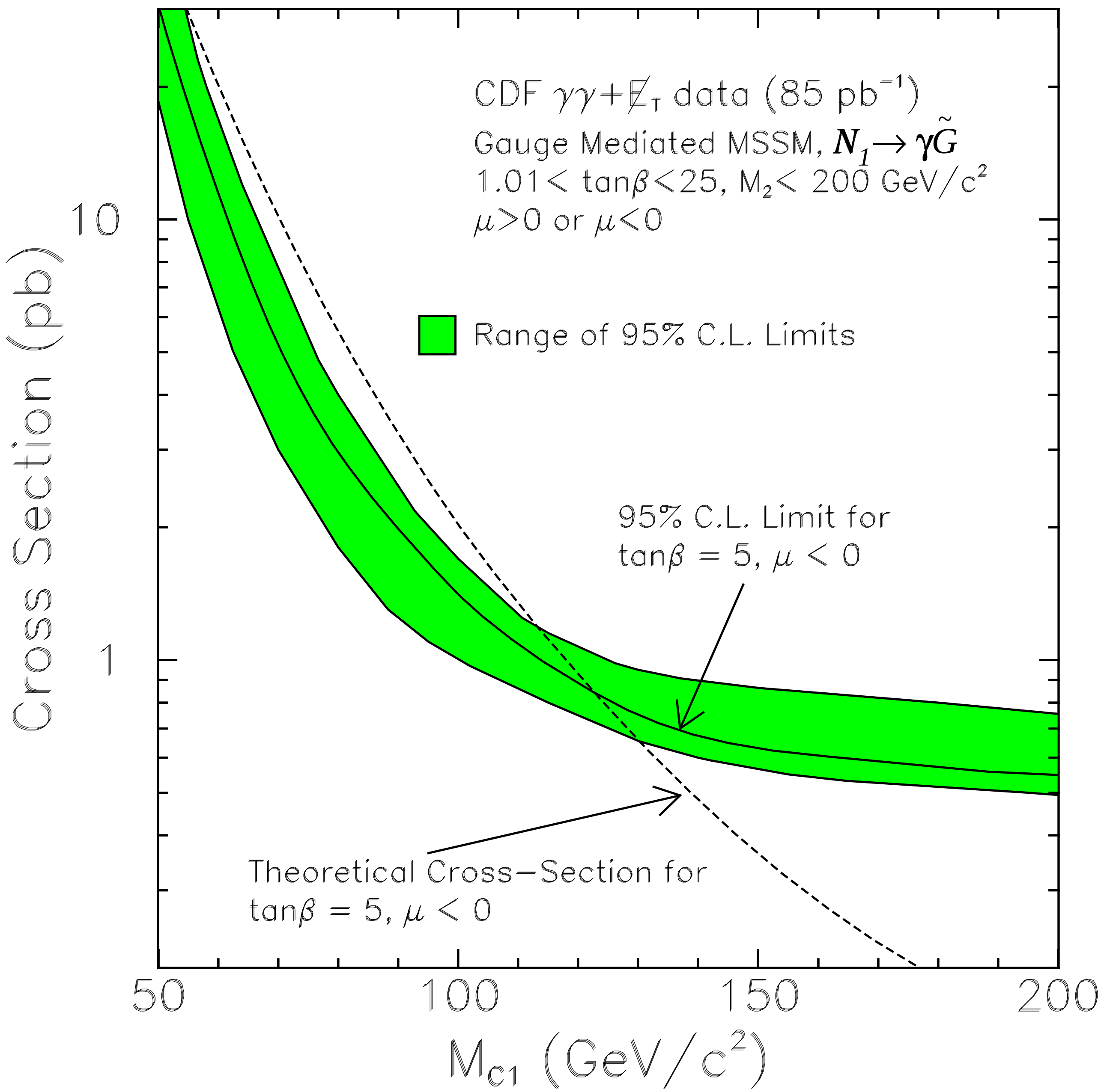


Comparison with SUSY

- Simulation using SPYTHIA
- U(1) x SU(2) gauge unification:
  - $M_1 = 5/3 \tan^2(\theta)\, M_2$
- Efficiency sampled for 50 sets of parameters
  - M_2 = 75, 100, 125, 150, 200
  - $\tan(\beta)$ = 1.1, 2, 5, 10, 25
  - $\mathrm{sgn}(\mu) = \pm 1$; magnitude set by EWSB

Exclusion Contours

- Dominant production is C_1N_2 and N_2N_2
- Excludes m(C_1) < 120 GeV at 95% CL

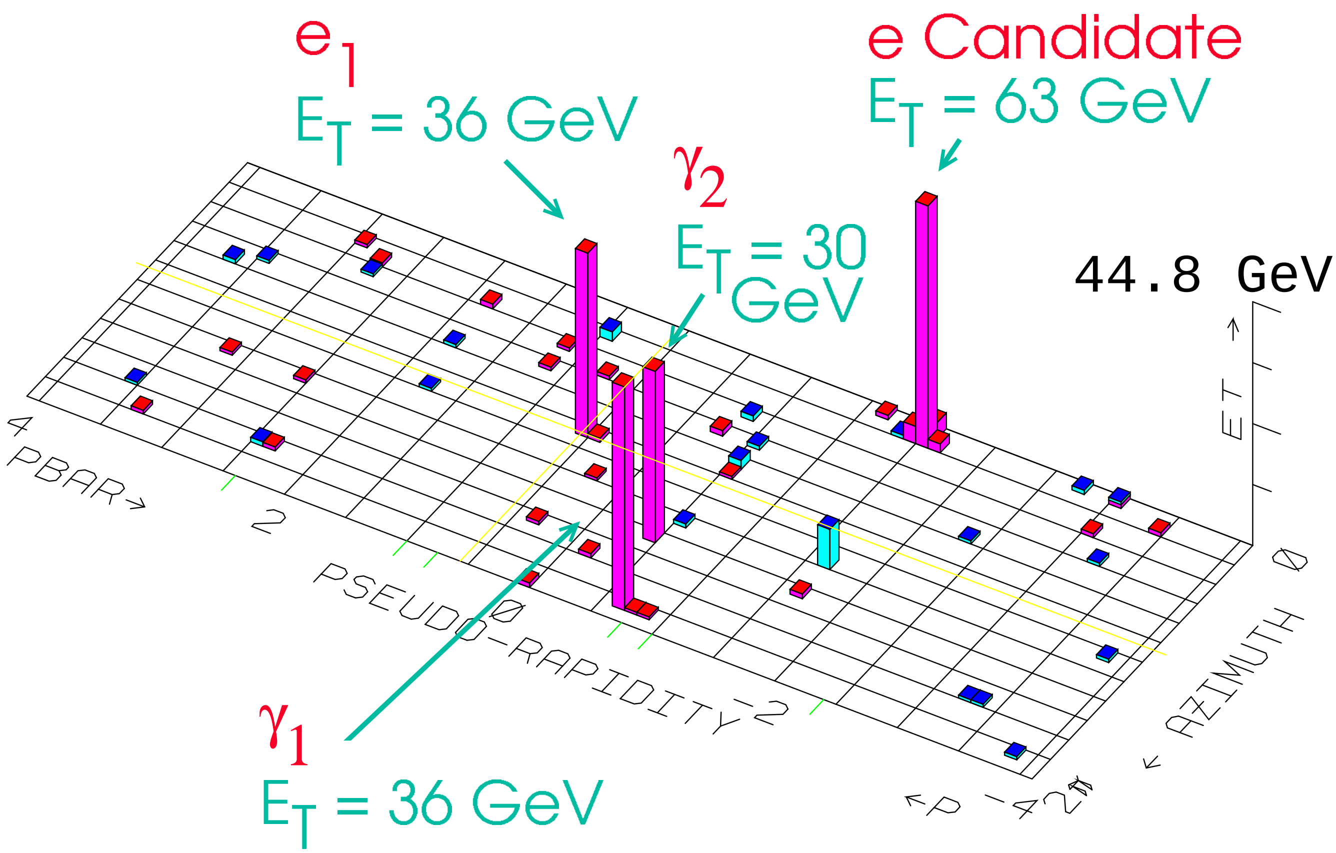


$ee\gamma\gamma$ ME_T Candidate

- Event has been analyzed in considerable detail
  - hep-ex/9806034
  - David Toback's Ph.D. Thesis
  - Many papers
- Compared with control sample of 1009 $Z \rightarrow ee$ events
- Interaction vertices
  - Primary: $z = +20.4$ cm
  - 4 vertices total, expected number = 2.5
- Central *e* and photons pass all criteria
- $ME_T = 55 \pm 7$ GeV, opposite $ee\gamma\gamma$ system, which has p_T of 48 ± 2 GeV

Exceptional Event

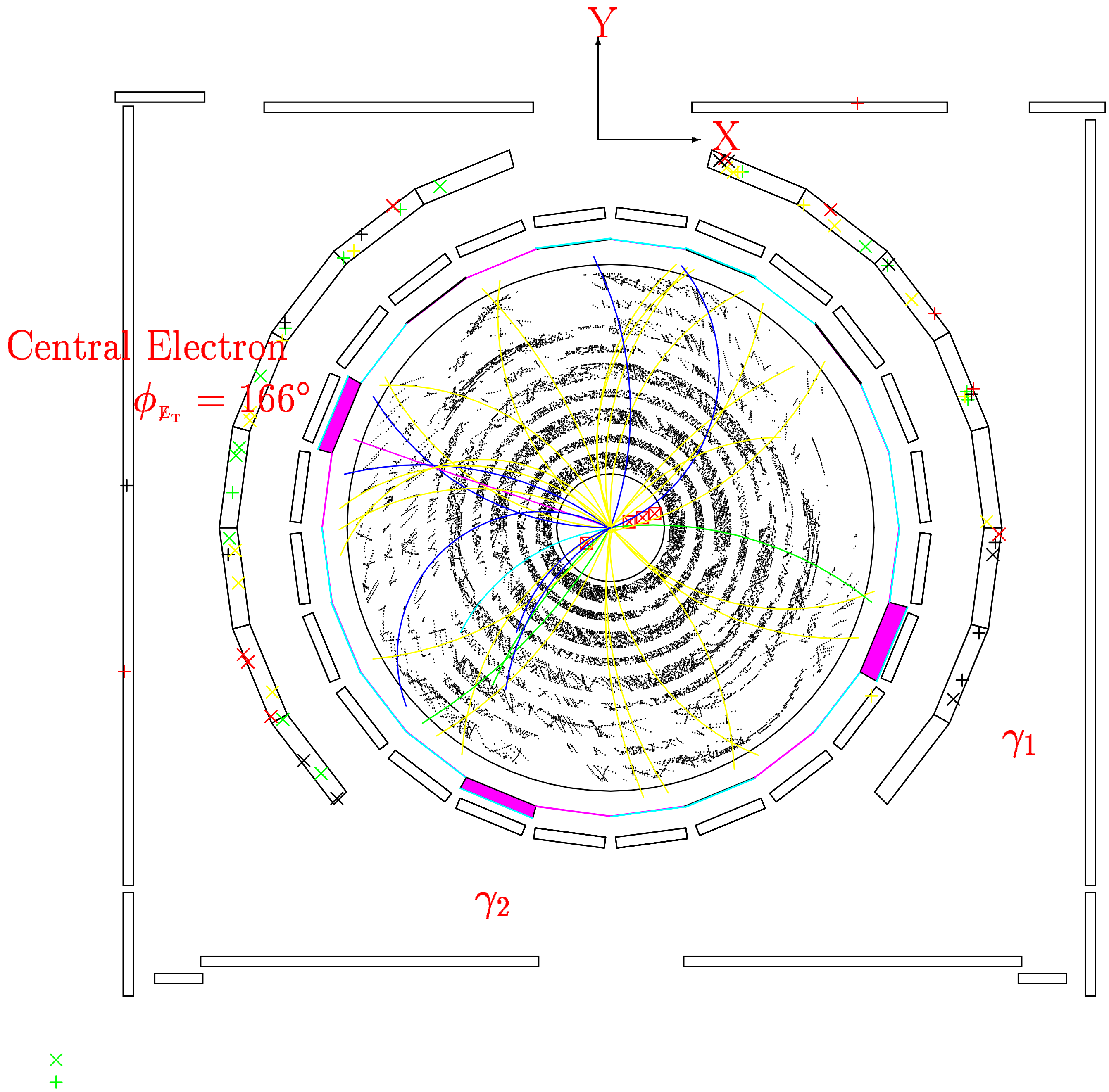
$ee\gamma\gamma\not{E}_T$ Candidate Event



$\not{E}_T$ = 55 GeV

Exceptional Event

$ee\gamma\gamma\not{E}_T$ Candidate Event



$ee\gamma\gamma$ ME_T Candidate

- Plug calorimeter *e* candidate passes all standard *e* ID criteria

Possible problem with electron interpretation

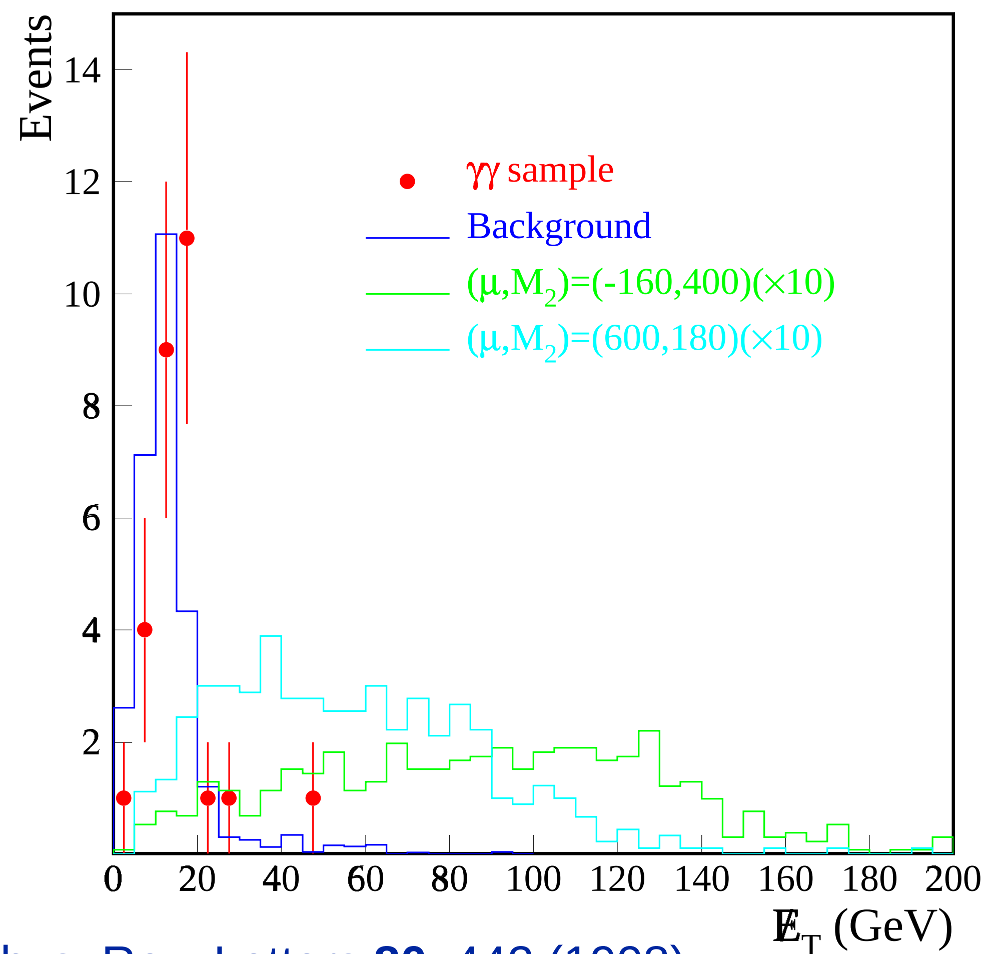
- Silicon vertex detector indicates cluster is not due to an electron: discrepancy in ϕ for plug *e* candidate — doesn't point to the calorimeter cluster
- Probability that an electron would have such a large discrepancy: < 0.3% at 95% CL.

$ee\gamma\gamma$ ME_T Candidate

- Possible plug cluster sources
  - Second interaction? No better association with any other vertex
  - No evidence for *e* bremsstrahlung or *e*-nucleus interaction
  - Photon? silicon vertex detector occupancy too high
  - Hadronic τ(1-prong)? Ratio of E_{HAD}/E_{EM} too small; probability of τ with such a value ~ few %
- "There simply is not enough information to establish the origin of the cluster"

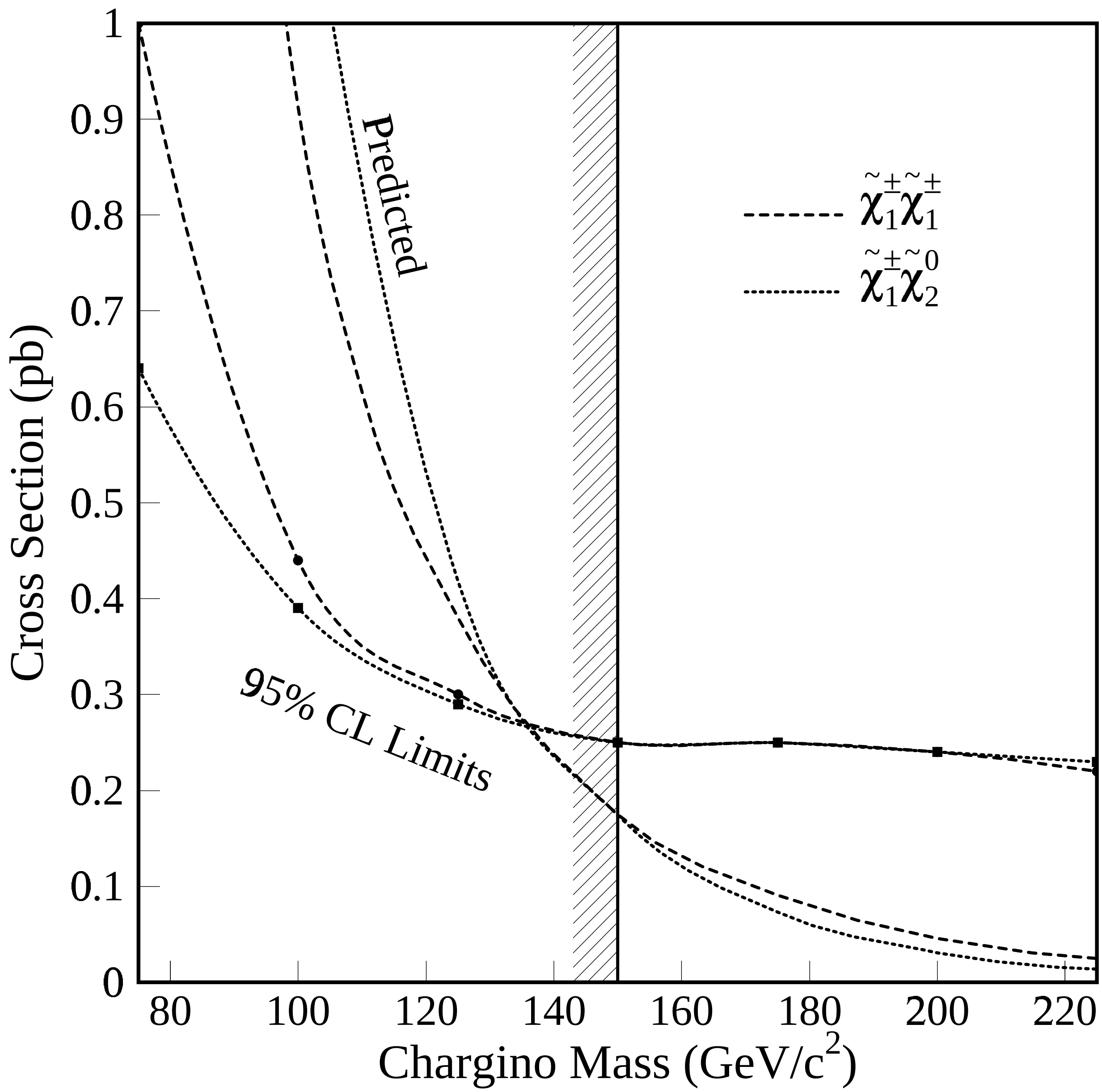
$\gamma\gamma$ ME_T Review

- DØ has published[1] a search for:
  - 2 γ, $E_T >$ 20(12) GeV, $|\eta| < 1,1$ or $1.5 < |\eta| < 2.0$
  - $ME_T > 25$ GeV
- 2.1 ± 0.9 events expected in 106 pb^{-1}
- Observed 2 events



[1] Phys. Rev. Letters **80**, 442 (1998).

$\gamma\gamma$ ME_T Review



Photon ID and Isolation

- γ = isolated EM cluster in calorimeter with lack of associated tracking chamber hits
- Calorimeter
  - Transverse and longitudinal shower profiles
  - E_{EM}/E_{Total} > 95%
  - isolation in calorimeter
  - efficiency (E_T > 20)

    92% $|\eta| < 1.2$

    89% $1.5 < |\eta| < 2.0$
- Tracking
  - No associated track in drift chamber
  - Reject cluster with tracker hits between cluster and reconstructed vertex

    80% efficient for γ

    rejection of ~220 vs electrons

γ ME_T 2j Search Strategy

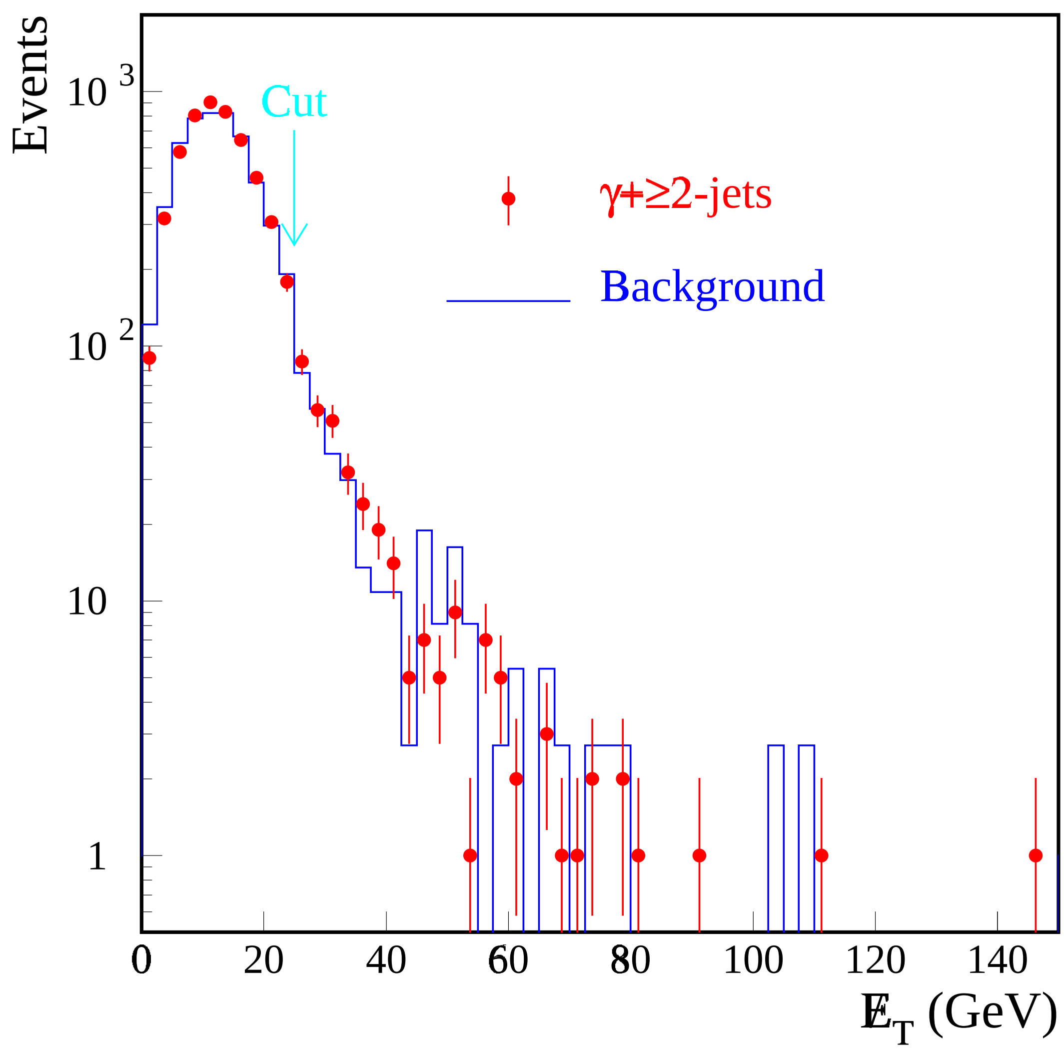
- The $\gamma\gamma$ ME_T analysis is very strong for GMSB models yielding 2 photons
- In radiative neutralino decay models it is weaker because it accepts only events in which two N_2 appear

Search for one high E_T photon, two or more jets, and ME_T

- Almost no SM backgrounds at the parton level
- Important instrumental backgrounds: apparent γ or ME_T from mismeasurement or misID of electron or jet
  - multijets, direct photons
  - *e* + jets (*W*, top) and ν + jets (*Z*)

γ ME_T 2j Base Sample

- Base sample selection
  - 99 pb^{-1} integrated luminosity
  - γ E_T > 20 GeV, |η|<1.2 *or* 1.5 < |η|<2.0
  - 2 or more jets, E_T > 20 GeV, |η|<2.0
  - ME_T > 25 GeV
- 378 events pass, 74 (≥3j), 10 (≥4j)



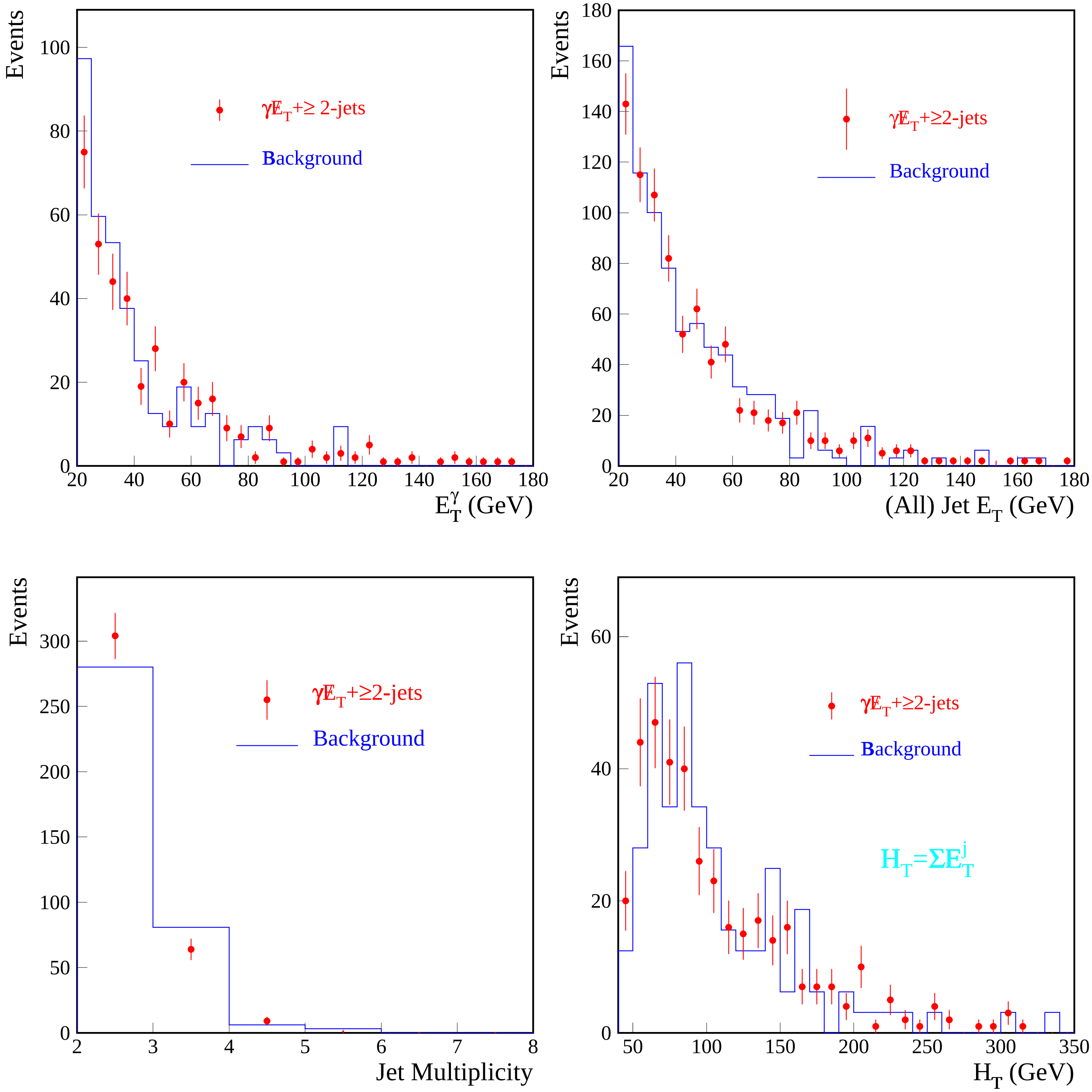
γ ME_T 2j Backgrounds

- Multijet events with photon misID and direct photon with mismeasured ME_T will mimic the signal
- ME_T mismeasurement modeled using multijet data with photon-like clusters
- Expected background: 370±40 events

- Events with genuine ME_T and with photon from misID of *e* or jet will mimic signal
- Backgrounds estimated from data, using known $P(jet \rightarrow \gamma) = 7 \pm 2 \times 10^{-4}$ and known electron rejection
- Expected background: 5.3±0.8 events

- Total: 380 ±40 events

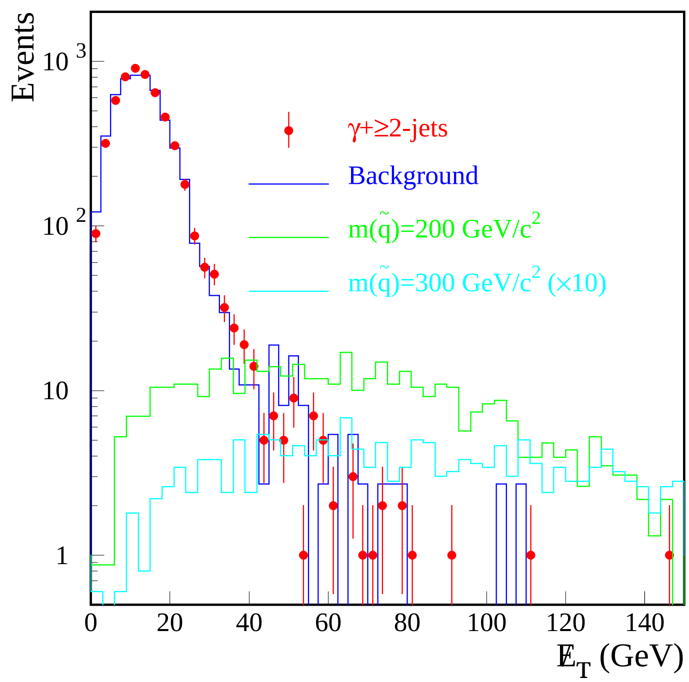
γ ME_T 2j Backgrounds



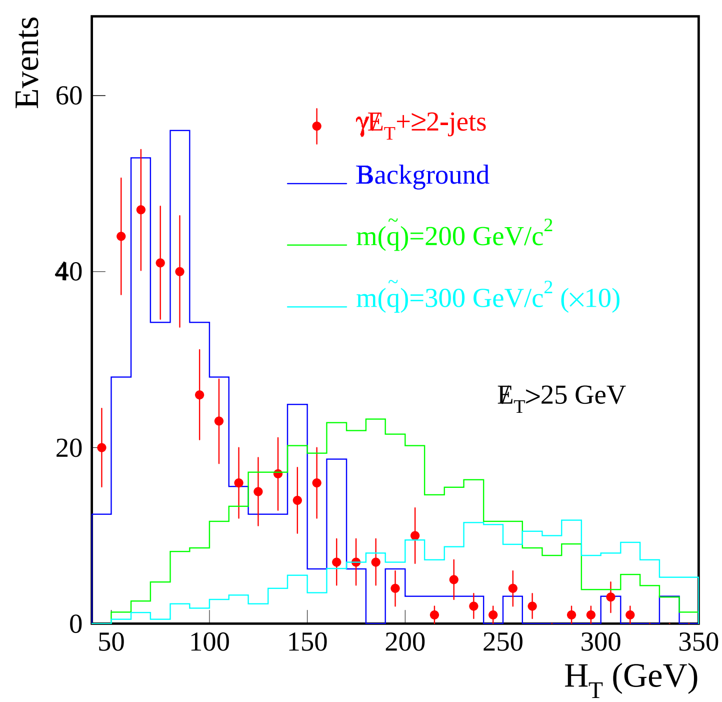
γ ME_T 2j Signal Simulation

- Production of squarks, gluinos, N_2 simulated with SPYTHIA
- MSSM parameters M_1, M_2, μ, $\tan(\beta)$ varied within constraints
  - $m(N_2) - m(N_1) > 20$ GeV
  - BR $(N_2 \rightarrow N_1 + \gamma) \cong 100\%$
- Sleptons assumed heavy enough not to figure in these decays
- Stop production (direct and in decays) ignored
- Study 3 cases
  - equal squark / gluino masses
  - heavy squarks / light gluinos
  - light squarks / heavy gluinos

γ ME_T 2j Signal Simulation



- Sample signal: equal squark and gluino masses
- Expected yield
  - 350 events for m_{squark} = 200 GeV
  - 20 events for m_{squark} = 300 GeV
- Optimize final cuts in ME_T - H_T plane



- H_T = sum of E_T^{jet}
- maximize $\varepsilon/\sigma_{backgr}$
- Final cuts

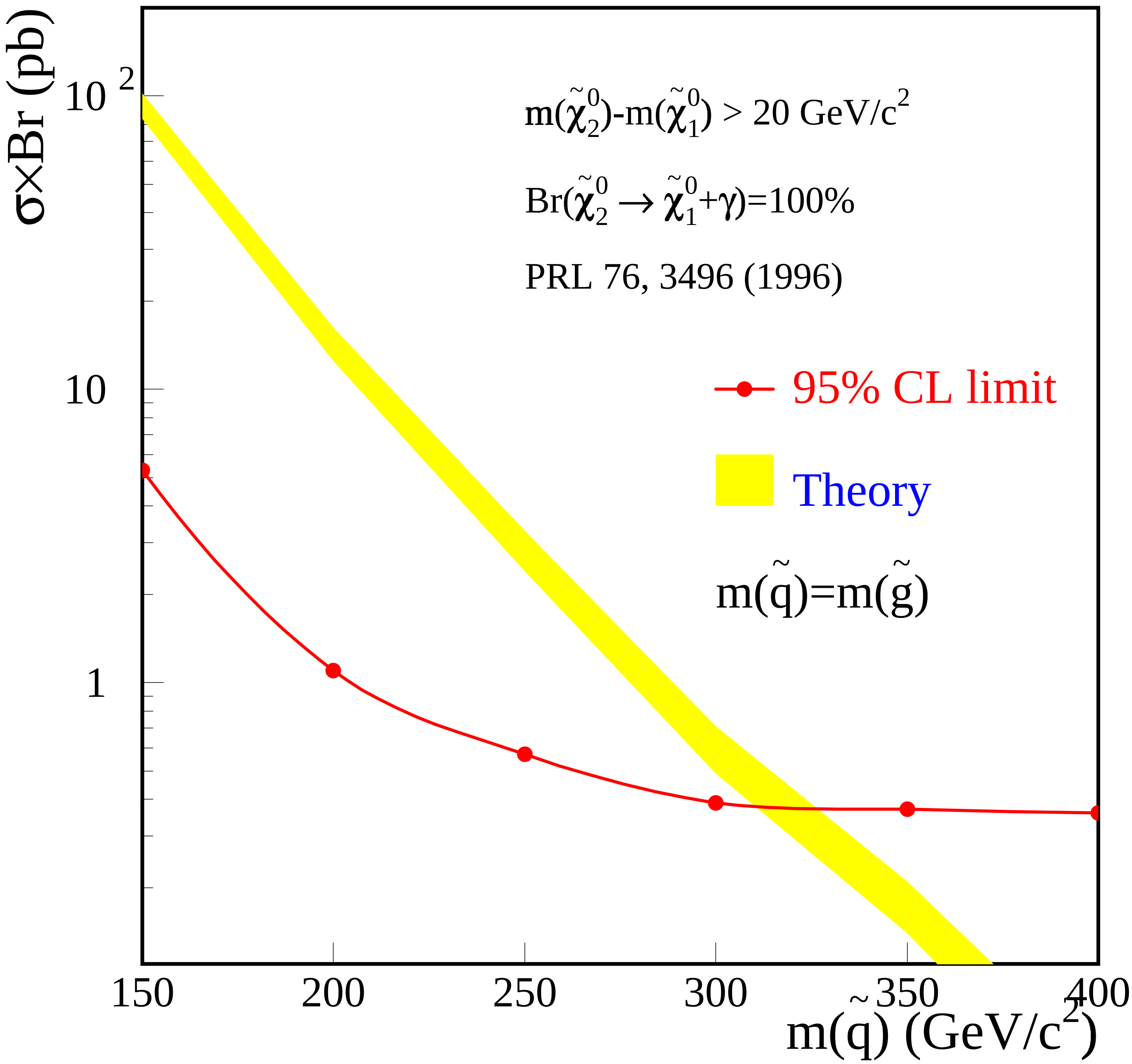
ME_T > 45 GeV

H_T > 220 GeV

- In data: 5 events
- Expected background 8±6

γ ME_T 2j Interpretation

- No excess observed: interpret as lower mass limit for squarks and gluinos



γ ME_T 2j Interpretation

- For equal squark/gluino masses: common mass > 311 GeV at 95% CL
- For light gluino / heavy squarks: m_{gluino} > 233 GeV
- For light squarks / heavy gluino: m_{squark} > 219 GeV
- Light sleptons increase production; light stop reduces production; varies limit by ±10 GeV

- No evidence for the models of Ambrosanio *et al*., but they are not ruled out if squarks and gluinos are heavy

SUSY with Photons Summary

- $\gamma\gamma$ ME_T analysis
  - GMSB and radiative decay models
  - CDF: m(C_1) > 120 GeV
    - observation of $ee\gamma\gamma ME_T$ candidate, hard to explain from SM sources
  - DØ: m(C_1) > 150 GeV
    - larger detector acceptance gives stronger limit

- γ ME_T 2j analysis
  - radiative decay model, when only one N_2 is produced
  - DØ: squark and gluino mass limits
    - $m_{gluino} = m_{squark}$ > 311 GeV
    - for light gluino / heavy squarks: m_{gluino} > 233 GeV
    - for light squarks / heavy gluino: m_{squark} > 219 GeV

Future Prospects

- Several sources for photons exist in SUSY models
  - GMSB
  - radiative decay
- Searches in multiple channels are consistent with SM expectations, except for one unusual event observed by CDF
  - $ee\gamma\gamma ME_T$ candidate very hard to interpret
- Run II will provide ~20 times the integrated luminosity, to two improved detectors
- Careful attention will be paid to photon production signatures

Only more data will answer the question of whether the $ee\gamma\gamma ME_T$ candidate is lucky observation of new physics, or an unlucky detection error